REPORT FROM MEGAVIND NOVEMBER 2012

STRATEGY FOR WIND TURBINE COMPONENTS AND SUBSYSTEMS

MEGAVIND

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1 PREFACE

In May 2006 the Danish government published a report on the promotion of environment effective technology and consequently established a series of partnerships for innovation in order to strengthen public-private cooperation between the state, companies and universities to further innovation processes within a number of technology areas. The partnership for wind power is called Megavind.

Since 2007 Megavind has developed a number of strategies that focus on activities to strengthen and accelerate innovation with specified recommendations for the state, universities and companies.
The Megavind steering committee consists of representatives from:

- Vestas Wind Systems A/S
- Siemens Wind Power A/S
- DONG Energy
- COWI A/S
- Fritz Schur Energy A/S
- DTU Wind Energy
- Aalborg University
- Energinet.dk (observer)
- Danish Energy Agency (observer)

The most recent strategies from Megavind is an offshore strategy with the target of a 50% reduction of Cost of Energy (CoE)[1] on offshore wind power plants in 2020 and a revised version of the strategy "Wind Power Plants in the Energy System". Here, a number of research, development and demonstration (RD&D) topics that aim to improve the correlation between wind turbines and the transmission grid are pointed out.

This report is Megavind's first strategy for components and systems in wind power plants. The strategy deals with the framework for the cooperation in the supply chain and a number of technological focus areas.

The strategy process has included two seminars for participants representing suppliers, universities and OEMs. The first was held in September 2011, where framework and technical efforts initially were discussed. The second was held in June 2012, where a draft of the strategy was reviewed and discussed. Moreover, a broader audience including suppliers, OEMs and universities, has reviewed the technical contents of the strategy.

The Danish version of the strategy exists only in a summarised version. The English version contains a chapter with a detailed description of the technical priorities.

1 Cost of Energy includes all expenses in a plant's life span (capital expenditure (CAPEX) and operational expenditure (OPEX)) in relation to the total energy production of the plant. The formula for calculating CoE is: Cost of Energy = (Annualized CAPEX + Annualized OPEX)/Annual energy output (AEP).

2 VISION AND TARGET

Megavind's vision is for Denmark, Danish companies and universities to maintain its position as the world's leading centre of competence within the field of wind power.

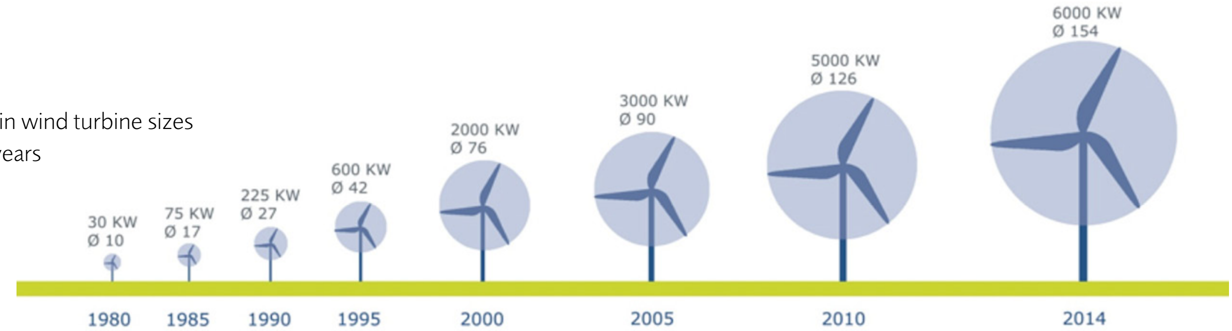
The Danish wind sector has a global leading position. In order to uphold the companies' competitive edge and at the same time maintain public and political support for large-scale renewable energy installations in Europe and the rest of the world, wind power must become economically competitive with fossil fuels by 2020.

The target of the strategy is to focus on the framework conditions and competencies needed for component and sub-systems suppliers to reduce cost of energy (CoE) and at the same time become more competitive.

CoE improvements

The sector has always strived to reduce CoE and has done so by 80% since the first turbines were installed more than 30 years ago[2]. The race to deliver still cheaper technological solutions has been imperative in making wind power competitive with fossil fuel technologies both in terms of price and efficiency. Increasing the size (capacity and rotor diameter), optimising efficiency and minimising consumption of materials have been the most significant factors in reducing CoE. For the first 20 years, the industry was forced to design and deliver a new larger turbine model every 1-2 years. Over the last decade wind power has become competitive with other technologies and there has been sufficient time to improve existing turbine models. Several of these have been upgraded with a larger rotor instead of a larger nameplate capacity.

Figure 1:
Increase in wind turbine sizes over 35 years



An example of improved CoE: By ensuring more documented durability (reliability) for a given component, it is possible to increase the availability of the turbine and thereby its annual energy production (AEP), and at the same time bring down both maintenance (OPEX) and the financial risk premiums (CAPEX) connected with this component. The component supplier will thereby get higher prices and/or the supplier can offer turbines with lower CoE together with the manufacturer.

However, there are still CoE reductions to be found in improving the turbine technology even though the onshore turbines are not expected to get significantly bigger. Especially design optimisation of the existing components and systems together with increased reliability are key to reducing CoE. Optimising the cooperation in the supply chain, including focus on core competencies and tied selling, optimising production processes and an increased use of design requirements, standards and benchmarking

2 Calculations from the Danish Wind Industry Association

also holds a lot of potential. Other ideas for improvement are linked with optimisation of transport, installation and service.

Another significant factor is the OEMs' Time to Market process i.e. the time it takes the OEMs to design and test a new prototype and test a 0-series before the turbine is ready for serial production. Many resources are required over a long period of time to design a new turbine. Optimisation of this process, so that e.g. time is brought down from 5 to 2 years, is a competitive parameter for the OEMs. The result itself, to produce a reliable turbine for serial production within a shorter time span, also contributes to CoE reduction.

Megavind is a partnership with a focus on research, development and demonstration (RD&D). Technology development and R&D cooperation will therefore be primary priority areas for this strategy. This especially applies to increased functionality and reliability for components and sub-systems but also to new turbine concepts.

With this component strategy, Megavind aims to move focus from the price of the component to the combined, relative cost related to the delivery of kilowatt hours. Also, methods for qualifying and targeting work on improving price service relationship related to the supply of the desired functions/functionalities are sought for.

Cost savings should also be found through optimisation of the functionality of the systems that the component is part of, and not only through making existing components cheaper. One could imagine a re-designed sub-system containing less individual components, where functionality and thereby CoE is improved.

A wind turbine consists of 15-20,000 components and many components and sub-systems affect each other indirectly, even though they are not directly connected. An example of this is the load transfer from the blades, which is transmitted to the entire turbine.

If e.g. more intelligent pitch- and yaw systems are developed, the loads from the blades can be reduced (and the rotor diameter may be increased). This can result in increased production or cheaper hubs and towers as the amount of materials can be decreased and thereby also the cost of the component.

2.1 FOCUS AND DELIMITATION

The main target of the strategy is development activities focused on optimisation and efficiency improvement within a given wind turbine concept. The target includes both improvement of cooperation in the supply chain and optimisation of systems and components.

The aim is to achieve improved quality in terms of better fulfilment of performance requirements and more reliable components with a longer life span. Always with a focus on reducing CoE, so that components and systems will not become more cost-heavy than necessary. Components with a better reliability than needed may be able to reduce reliability with possible cost reductions as a result. However, this must be evaluated from a sub-system perspective. These activities can both result in larger production (improved function and availability), efficiency improvement (lower costs to achieve a given function or greater AEP) and reduced operation costs through improved reliability.

Efficiency improvement of the production (serial production/installation) can also contribute to cost reduction. Many suppliers have invested in valuable machinery in order to reduce man hours and salary costs in the production. Production optimisation itself, however, is a very comprehensive subject, which will not be dealt with thoroughly, as this strategy deals with innovation and development. Production friendly from a standardisation and modularisation perspective (see chapter 3.3.2) can be a desired quality for components and systems and therefore relevant in this context. This also applies to initiatives ensuring a consistent quality in production and thereby reliability. Here, focus must be on control requirements for components and systems are not over specified, so suppliers are met with greater costs than necessary.

Expenses for installation of turbines such as transport, cranes and related services are only indirectly included in this strategy. Installation-friendly designs of components are an area that, however, can have great impact on CoE and is therefore relevant in the development process.

Operation and maintenance represents a large potential of improvement and is therefore fully included in the strategy and closely connected to the optimisation of a given wind turbine concept (reliability and life span).

PHOTO: ANDRESEN TOWERS A/S

3 STRATEGIC RECOMMENDATIONS

The component strategy includes activities within four research areas:

- **Value chain cooperation.** The cooperation in the supply chain between energy companies, OEMs and suppliers - as well as supplier to supplier

- **The individual company.** Each individual company's resources and competencies - including development of new competencies and business areas

- **Framework conditions.** Includes a number of different conditions that determine the companies' development opportunities (markets, competition, advanced demand, knowledge from R&D, education, standardisation and information infrastructure, test and demonstration facilities)

- **Optimisation of functions.** Technical research areas that holds a potential for CoE reduction

It is expected that suppliers of components and systems will be able to present a significant part of the possible CoE improvement through optimisation and efficiency improvement on these four areas. The main question is what activities are needed in order to create those improvements in function, reliability and life span, which ultimately result in a CoE improvement.

3.1 COOPERATION IN THE SUPPLY CHAIN

Overall target: *To create a basis for more efficient, innovative cooperation in the supply chain.*

Many consider a company's competitive power to be closely connected with its innovative activities. This being innovation in the company alone, in cooperation with other companies in the supply chain or the company's cooperation with universities, buyers or outside the supply chain - framework conditions. All these areas hold potential for technical innovation and possibilities for improvement of processes. The strategy focus is therefore to improve supply chain cooperation with regard to development activities.

The tendency in the industry is that a future supply chain will be divided into hierarchies and where assembly of sub-systems will be outsourced to key suppliers. The OEM strategy is to reduce the number of suppliers to better control the quality of the delivered systems. The result will be a small group of companies that will become system suppliers to the OEMs and be closer involved in the development process of the OEMs. A large group of companies, at a lower stage in the hierarchy, will then move further away from the end user (the OEM) and will engage in development activities with the system suppliers instead.

Structural changes in the supply chain

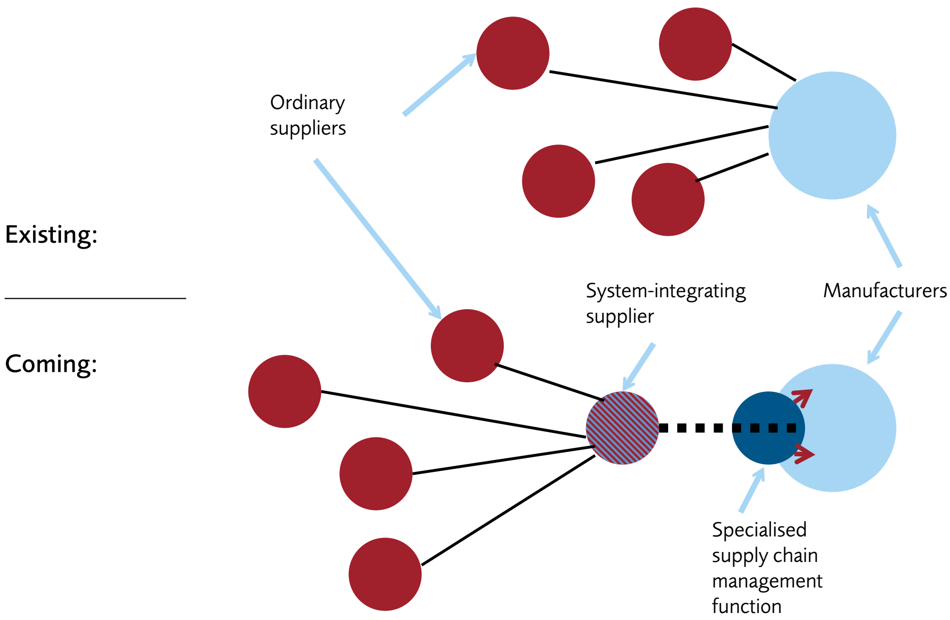


Figure 2:
Suppliers will to a higher extent be divided, so that some will become systems integrators and be responsible for the cooperation with their sub-suppliers for the delivery of systems and sub-systems to the OEMs (Source: Houmann & Drejer, Denmark – The Wind Power Hub; Transforming the Supply Chain).

There is room for improvement in the communication and cooperation processes between OEMs and component- and systems suppliers. Exchange of knowledge must be prioritised to avoid misunderstandings between supply chain tiers. This cooperation is one of the pivotal points of the strategy. Improving exchange of knowledge including knowledge of turbine operation and system interdependence is a part of the precondition for improving components and systems and can have significant impact on the reduction of CoE.

3.1.1 COOPERATION ON DEVELOPMENT IN THE VALUE CHAIN

Targets:

- Description of development processes that promote innovation and improve efficiency and in this way contributes to a CoE reduction.
- Improvement of cooperation between suppliers and between suppliers and OEMs regarding function-based systems.
- To create the basis for clear communication between the companies in the value chain regarding development and production of components and systems via function-based, well-defined and common terminology.

OEMs have traditionally designed new prototypes themselves and delivered specifications to suppliers with requirements to function and quality of the individual components or systems. Suppliers possess great specialised knowledge about the individual components that is not fully exploited in the development of new components and systems. Only suppliers of key components have traditionally been involved in the design and development process of new components or systems.

Exchange of information is also limited because OEMs are not sharing sufficient data with the suppliers. A reason for this could be that many suppliers deliver to various OEMs and core knowledge can potentially be passed on to a competitor. There are however plenty of ways to improve development cooperation without exchanging vital data. Another reason could be that many suppliers need a more extensive knowledge of basic wind turbine technology and systems before a meaningful dialogue can take place.

Supplier network of Envision Energy seen from a supplier perspective

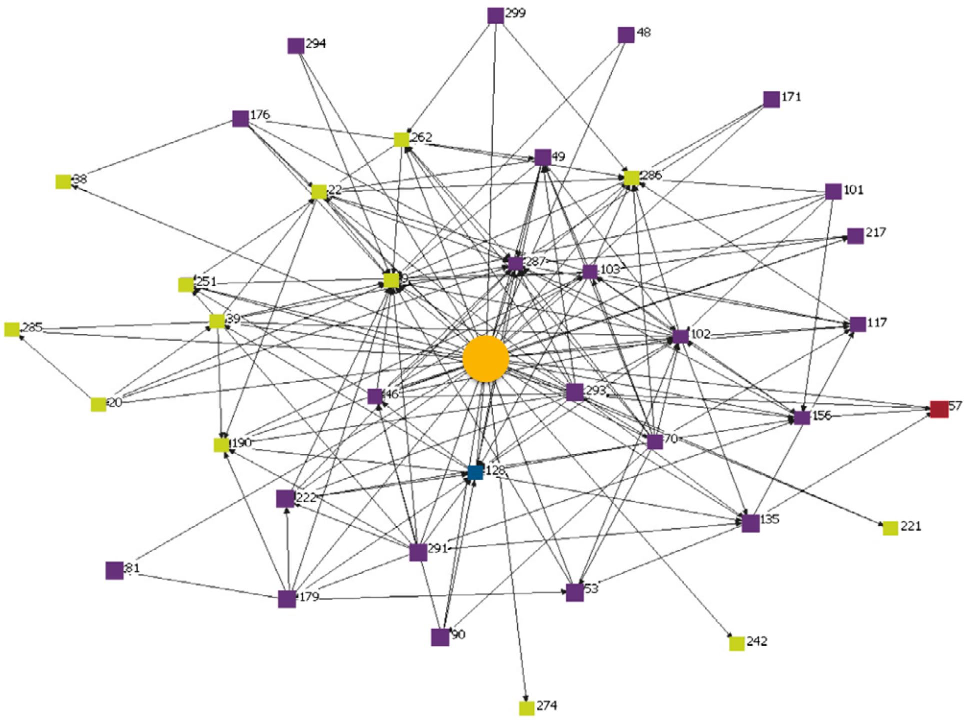
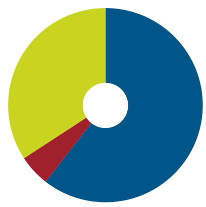


Figure 3:
The figure shows an example of Danish suppliers that have several OEMs as customers (Source: Houmann & Drejer, Denmark – The Wind Power Hub; Transforming the Supply Chain).



- Does not share knowledge with Siemens or Vestas
- Shares knowledge with Siemens and Vestas
- Shares knowledge with Vestas
- Shares knowledge with Siemens
- Envision Energy

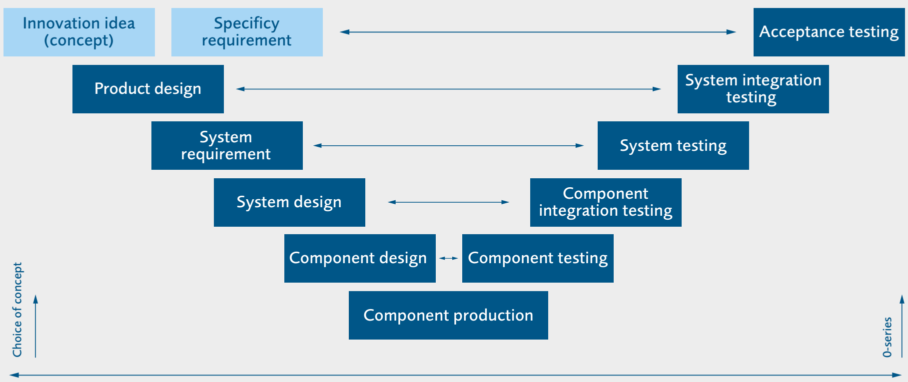
The companies in the industry all use documented development processes. Many of these share similarities and ensure that the product is fully tested before production. However, differences in terminology and requirements for documentation of different tests can occur. These differences can create noise in the communication between OEM and supplier.

V-model

The V-model is a good example of a structural description of the elements included in the optimisation process of the cooperation development in the value chain (between OEMs on one hand and suppliers of systems and components on the other). Depending on the complexity, modifications of the process will occur where the number of phases are reduced.

The V-model is used on a component or in a system. In a combined development process for a new turbine model, the model will be used repeatedly on a system level. The V-model can also be used in the description of the cooperation between the developer/owner on one hand and the wind turbine OEMs and suppliers on the other.

The V-model has the advantage that an on-going verification takes place in connection with the various phases of the development process. Resources will therefore not be spent on development activities that do not meet the basic requirements.



Specifications from OEMs can include requirements for documentation of conditions that suppliers either cannot interpret or do not know how to test for. How can you document 20 years of reliability for a hydraulic cylinder? A way of solving this problem can be that suppliers of sub-systems together develop a dictionary, where terms and terminology is defined, including how tests are run and documented. It is also possible to imagine adjusted specifications from OEMs, where design of test and documentation for this is clearly defined.

An important element in strengthening the interaction in the supply chain is to improve the framework through:

- Common verification- and validation methods (standardised testing and measuring methods)
- Common set of tools (e.g. adjusted HALT/HASS/HAST/QALT or FMEA methods) [3]
- Common terminology regarding function requirements (specification of functions)
- Common definitions by detailed technical requirements (technical specifications)

A common terminology must have references to existing standards, especially including the IEC 61400 series. Moreover, it could create basis for a Danish initiative of the development of an information standard for wind technology (see section 3.3.2).

RECOMMENDATION: The development of a dialogue on a well-defined and common terminology is initiated. Furthermore, a common validation tool will be developed. The development should be carried out within the framework of one or more concrete development projects on the basis of those sub-systems mentioned in section 3.4. The Danish Wind Industry Association will initiate these activities.

3 HALT: Highly Accelerated Life Test. HASS: Highly Accelerated Stress Screening. HAST: Highly Accelerated Stress Test. QALT: Quantitative Accelerated Life Test. FMEA: Failure Mode Effect Analysis.

3.1.2 SYSTEMATIC EFFORT TO IMPROVE RELIABILITY

Target:

- Development of common methods for estimation, evaluation and documentation of reliability.

Important elements in improving reliability are:

- better identification of critical, dimensional determining conditions
- methods for evaluation of reliability of critical components and sub-systems
- common methods for documentation of reliability

This includes a description of common methods for verification of reliability on the basis of tests. Apart from estimation of reliability in the form of failure rates, it is also important to gain information about which uncertainties are determinative for the reliability of the components and thereby the predictability of their life span. It is important for suppliers of the individual sub-systems to have solid knowledge about each other's components and about the interdependence that exist between these in any given system. A failure in component A or B can inflict failure in component E.

A collection of past experiences from companies that understand the operation of a wind turbine (OEMs and owners) is needed, and the results of completed reliability studies of reliability must be used. It is important that experiences and results are made comparable so that there is a common understanding of this in the supply chain.

Planned service and in connection with operation and maintenance is an important expense factor and is therefore included in the design and development process. Documenting reliability makes up a large future challenge and must be seen from a life cycle perspective, where CoE is maximised and where accurate predictability of the life span can have greater importance than a low failure rate. In order to plan condition based preventive maintenance optimally, data on the indicators preceding a break-down is needed. Information on failure rates alone is not sufficient.

There are other industries that have been working longer with reliability and where methods and tools can be found to benefit the wind industry as well.

RECOMMENDATION: Methods for estimation, evaluation of life span and reliability as well as for consistent reporting on reliability must be developed. This can be done by having an increased focus on R&D in reliability and tests at the universities and by implementing a project focusing on methods and tools for documentation of testing and reliability. Representatives from the industry and universities will initiate these activities.

3.2 IDEAL COMPETENCIES

Component- and system suppliers have very different levels of knowledge when it comes to wind turbine technology. Some companies have been supplying components for turbines since the birth of the industry, while others have just entered into the market within the last decade, where growth rates have been particularly high. Development of competencies will therefore be an important factor for a number of suppliers. Ideal competencies are in this context defined as competencies that both OEMs and suppliers must have in order to perform as qualified cooperative partners. In this strategy focus will primarily be on technical knowledge and development processes.

Overall target: *To help present and help potential suppliers become qualified suppliers and that OEMs develop the competencies to help suppliers with this improvement*.

The group of suppliers consists of e.g. companies with a long tradition of manufacturing components and systems for wind turbines. As previously mentioned, deliveries have been mainly production by order with detailed specifications from the OEMs. Traditionally, there has been an ad hoc-based dialogue about problems and the suppliers' specialised technological knowledge of their products have not been exploited optimally in the development process. However, further upgrading of know-how is needed for a number of suppliers if they are to fulfil the role as systems- or sub-systems suppliers.

Suppliers need to increase focus on their competencies within component testing and verification. This can be done by employing engineers with specific knowledge in testing and documentation or by using external consultants for test design and documentation. The suppliers can also strive to acquire a more fundamental knowledge about the turbine in general and the environment that their components or systems must function in.

OEMs must become better at creating requirements specifications with guidelines for test and verification and be prepared for a closer dialogue about this, so that suppliers have a benchmark to go by.

"There is a price to pay for having closer ties, and that price will often involve having to comply with well-meant, but firm, guidance on optimising products and processes, so, all other things being equal, I believe that we will be moving towards the ways of the automotive industry [...]. That, in turn, places demands on players like us [OEMs] that we must be able to act as a sounding board to them [the suppliers], and we are not properly equipped to do that yet" (Quote from the report: Denmark – The Wind Power Hub; Transforming the Supply Chain, Houmann pp. 58)."[4]

RECOMMENDATION: Focus on test and verification activities at the universities, so that engineers are educated with a specific testing background that includes design, specification, reliability evaluations etc. These engineering fields of study are offered at foreign universities.

4 Quote from the report: Denmark – The Wind Power Hub; Transforming the Supply Chain, Houmann pp. 58.

3.3 FRAMEWORK CONDITIONS

Framework conditions can, in itself, contribute to create competitive advantages for the companies. Access to state-of-the-art test facilities can make a considerable difference for the competitiveness of both the OEMs and suppliers. Especially companies that do not have the resources to establish large test facilities on their own will gain advantages with the access to test facilities and additional consulting services. They will be able to test and document the products in large systems. Furthermore, common standardisation documentation will benefit the industry, as it will ensure a similarity in the product quality.

3.3.1 TEST AND DEMONSTRATION OF COMPONENTS AND SYSTEMS

Target:

- Improvement of the possibilities of testing and demonstration of components and systems including:
    - Electrical systems
    - Hydraulic systems
    - Control systems
    - Cooling systems

The suppliers' possibilities for full-scale testing and demonstration (testing under real circumstances) are today typically dependent on cooperation with the OEMs.

Better opportunities are required through the establishment of test facilities. Several facilities are being established, but the financing of the facilities is a mutual challenge. Facilities and their financing can with a mutual benefit be organised by suppliers and relevant knowledge institutions in cooperation.

One possibility is that a group of suppliers establish a consortium and buy a wind turbine to carry out tests at system level. This sort of cooperation already exists, as a small group of suppliers have bought a turbine at the Høvsøre Test Center. Another possibility is to establish collaboration with a turbine developer or owner and gain access to do system testing on one of their turbines.

Wind turbines are installed all over the world and in very different environments, from -40 to +50 degrees Celsius, in arctic areas, in deserts and at sea. There are therefore great demands on components' abilities to handle cold, warm, humid and corrosive climates.

Several suppliers perform climate tests on their components, but it would be beneficial to many, if suppliers have the possibility of large system testing in a large climate chamber.

RECOMMENDATION: The establishment of facilities for large-scale climate tests.

RECOMMENDATION: That the suppliers to a larger extent cooperate with turbine owners in testing sub-systems on existing turbines.

3.3.2 STANDARDISATION

The term standardisation covers both public standards (IEC, ISO, DS, DIN etc.) as well as standardised products, i.e. an attempt to gain advantages by minimising the number of variants. Public standards often describe requirements for quality and safety.

Target:

- To promote work on standardisation and modulation of components and systems, so that the unit price is minimised, functionality is optimised, flexibility increased, the reliability is optimised, and there is a consistent quality in the production.

Another applied terminology is based on the purposes of standardisation:

- **Compatibility and interfaces.** Standards in this area determine the conditions for whether a product can function in the context it is placed in. It can be simple geometric compatibility and it can be a standardisation of data interfaces/couplings.
- **Minimum quality, fundamental safety requirements.** This is often the content of public standardisation. These standards that are also typically used as a basis for regulation of health, safety and environment. They are also applicable as basis for specification of requirements from the buyer as measuring methods typically are included in the description.
- **Reduction of number of variants**. Deals with economy of scale in the production with a larger number of units in serial production and thereby a reduction in production- and logistics expenses. Modularisation is one way of achieving this.[5]
- **Information standards.** Contains standardised definitions of a number of frequently used terms and can thus contribute to the anchorage of a shared language in the form of a special industry terminology used in technical and commercial documents.

Standards and standardisation can occur from various types of processes:

- **De facto standardisation** that typically occurs when a market-leading player defines standards and others subsequently use these.
- **Industry standards** based on cooperation between players in a certain industry or sector without participation from standardisation institutions.
- **Public standards** managed by international (IEC, ISO) and national (DS, DIN) standardisation organisations.

The common technical standards are not obligatory for the companies. They can be made obligatory by public authorities (through rules and regulations) or by a buyer (through requirement of meeting certain standards).

The use of common, generic components and systems that are not especially fitted to the use in wind turbines (off-the-shelf-products) is not included in standardisation activities. A standardisation process for such components can in some cases be relevant to describe the stress that the components must withstand including required measuring methods.

5 Modularisation is a way of splitting products and processes into smaller and relatively independent functional units – also called modules. A great flexibility can be achieved in both production processes and chain of delivery with the right balance between module function and interface standardisation of the modules.

A development of specific standards related to components and systems is needed. Therefore, activities should be initiated, focusing on development of specific wind power standards for components and systems, where there is a broad consent to this. These standards should describe safety and quality.

The use of standard components will to a high degree contribute to reducing CoE, because it will create a new economy of scale in the production. The wind industry generally operates with very small quantities, for many companies only a few thousand units a year is not enough to seriously reduce production costs.

Not all components can be standardised because of different designs and technology choices made by the OEMs. However, there will be a lot to gain, if the functions that are not connected to the individual OEMs main competencies are standardised, for example common standards for towers. OEMs could also choose to agree on the same diameter for the root of the blade and using the same type of bolts. This would have an effect on the production of hubs etc.

Compatibility and interfaces is one focus area of the wind sector. Examples of this type of technical standardisation are geometric compatibility and standardised data interfaces between different components. Standardised methods for function verification of components and systems, is another important focus area. The stress that components and systems meet in the turbine is specific for wind power technology and adapting generic test and verification methods to wind technology will be beneficial.

Focus should be on the standardisation of component and system functions and thereby provide suppliers with the opportunity to deliver innovative solutions of how this function is achieved. This process has already taken place for components in wind turbine towers.

A public programme with support of a proactive effort within standardisation directed at chosen components and systems will support the suppliers' development of competencies.

RECOMMENDATION: Activities that can support wind power specific standardisation and modularisation with a focus on compatibility and interfaces as well as methods for verification of functions containing both industry standards and public standards. The Danish Wind Industry Association will initiate these activities.

3.4 TECHNICAL FOCUS AREAS

Some turbine sub-systems hold greater potential for CoE reductions than others. The target in this section lists some of the areas with most potential.

Target:

- Optimisation of design/load distribution
- Substitution of traditionally used materials with new solutions (lower weight, cheaper, better qualities)
- Optimisation and improvement of the turbine control system (optimised load distribution, improved and more precise measuring of the wind)
- New components in the electrical system

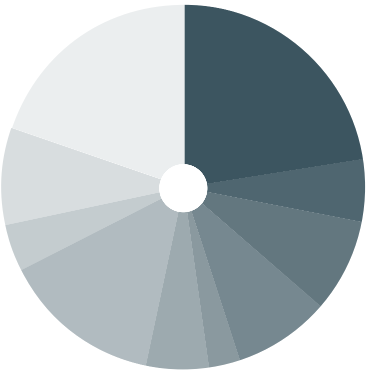
The individual components or sub-systems represent very different levels of the overall cost price for a wind turbine. The most cost heavy components are blades, the tower and the gearbox (for geared turbines), and an optimised design will respectively be able to increase production, reduce costs of materials or increase reliability. This will help reduce CoE, when it comes to the purchase price of the wind turbine (CAPEX).

Other components are not as cost heavy, but they are expensive in the life span perspective of the turbine, because they cause turbines to fail and thereby reduce the production. This has been the case for bearings on different locations in the turbine. Sensors, with a very low cost price, have also caused turbine failure with significant production loss as a result. Improved reliability or accurate life time assessment of individual components and systems will result in preventive component replacement in connection with planned maintenance reducing operation and maintenance costs.

Optimisation of design or function of individual components and systems can still contribute considerably to reduce the CoE even if these do not dominate in the following pie charts.

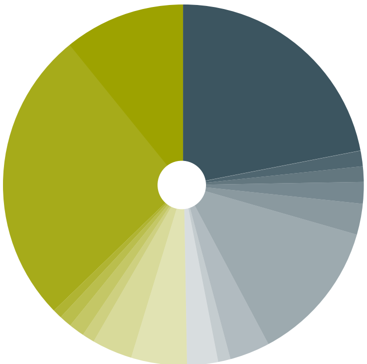
PHOTO: SIEMENS AG

Division of CAPEX on components and subsystem



- Blades 20%
- Hub and pitch system including bearings 8%
- Load control, sensors and control system (PLC) 4%
- Gearbox 14%
- Main bearing and main shaft arrangement 6%
- Transformer 3%
- Converter 8%
- Generator & remaining electrical system 8%
- Structural Elements 6%
- Tower 23%

Figure 5:
Megavind's estimate of the division of CAPEX in % of main components and subsystems in a wind turbine. The figures are an estimated average of the costs for turbines of 1.5-3 MW



- Blades 22%
- Rotor hub 2%
- Rotor bearings 1%
- Main shaft 2%
- Main frame 3%
- Gearbox 13%
- Generator 3%
- Yaw system 1%
- Pitch system 3%
- Power converter 5%
- Transformer 4%
- Brake system 1%
- Nacelle housing 1%
- Cables (turbine to substation) 1%
- Screws 1%
- Tower 26%
- Other 11%

Figure 6:
EWEA's estimate of the division of CAPEX in % of main components and subsystems in a wind turbine based on a Repower MM92 (2 MW) turbine (Source: Wind Directions, January/February 2007)

The following section lists a number of key components and systems in the wind turbine and how these can be optimised.

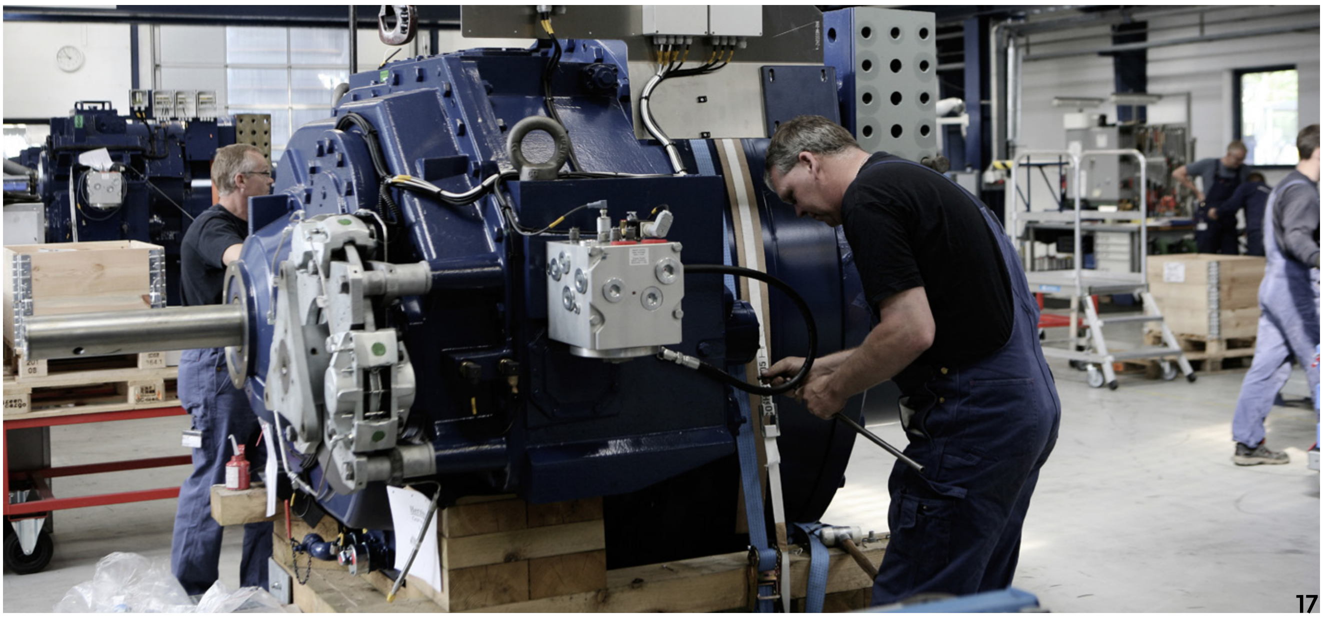


PHOTO: VESTAS WIND SYSTEMS A/S

3.4.1 BLADES

Functions

The blade has the following main functions:

- Convert kinetic energy from wind into torque and rotational motion around main shaft axis with an optimised load envelope
- Transfer lightning to structural system

Targets

Two separate targets have been put forward in order to get benefits of both current pitch actuation technology and to make sure that the blade system is prepared for future technology developments.

Develop a blade that can give 10% more annual energy production within the same load envelope as today's wind turbine technology using innovative passive and active control methods.
Develop a blade where future aerodynamic power and load regulating systems can be implemented.

Current Solutions

There is a close link between the manufacturing processes and the structural blade design. Today these different technologies dominate the market.

- Open mould manufacturing using resin transfer moulding to make two shell elements and a web. Parts are then bonded together with longitudinal bond lines.

- Spar and shell design where the main structural strength is put into a spar manufactured using a winding method on a mandrel combined with two shells giving the aerodynamic profile.

- Closed mould design where the resin transfer moulding is taking place in a mould that is made up of two parts and special cavity elements resulting in a structural design without bond lines.

Optimisation of blades needs to be done with very careful consideration of structural aspects as well as manufacturing possibilities and limitations.

The blade has a significant impact on the CoE due to high CAPEX, significant impact on power production and also due to potentially high OPEX repair costs in case of blade failure.

Emerging Technologies

There is a multitude of emerging blade solutions many of them driven by the opportunities of implementing some of the potential aerodynamic load and power regulation solutions, but also blade technologies that are independent of these systems.

Emerging technologies includes:

- Aero-elastic tailoring where deformation patterns are optimised to give increase aerodynamic efficiencies and better control of load and deflections

- Passive regulation where there is coupling between bending deflection and twist or lift.

- More automated manufacturing processes

R&D Projects

There needs to be a very close tie between the aerodynamic power and load regulation (APLR) technology projects and the projects that are to be executed on blades.

Some of the blade specific research areas that the industry should focus on include:

- Optimisation of blade design to improve the robustness towards manufacturing variation and thereby reducing OPEX (e.g. blade designs that are inherently robust towards lamina wrinkles and in relation to aerodynamic performance are robust towards manufacturing tolerances and dirt).
- Blade designs and manufacturing processes with increased process automation to reduce cost and product variation.
- Passive control where there is a coupling between deflection and lift (either through stall or through significant twisting).
- Development of lightweight flexible blades (while ensuring that there is sufficient tower clearance and proper response to pitch actuations).
- Development of low cost high module fibres (e.g. low cost carbon or S-glass fibres).
- Manufacturing of blades in a more modular approach (like in aircraft manufacturing).
- Integration of APLR systems into blade structures.
- Fundamental material research to enable flexible load carrying structures.
- Improved connections between composite structure and pitch bearing.
- Aerodynamic research on alternative designs and components (winglets, flat back profiles, vortex generators, high solidity blades)
- Aerodynamic tool development to enable accurate computation of impact of new technologies.

PHOTO: LM WIND POWER

3.4.2 SYSTEM FOR AERODYNAMIC POWER AND LOAD REGULATION

Functions

The system for aerodynamic power and load regulation (APLR) has the following main functions:

- Control torque on drive train during normal power production above rated power
- Control rotational speed through blade pitch during normal power production above rated power
- Reduce rotor speed during normal and emergency stop situations
- Control torque during low voltage ride through
- Reduce structural loads on wind turbine through independent, cyclic or collective actuations of blades or aerodynamic control devices

Target

The target is to develop an APLR system that shall give 25% more annual energy production within the same load envelope as todays wind turbine technology.

It is necessary that the APLR system can operate for 20 years without significant repair and service costs and that the new technology may not increase the price of the blade and APLR system with more than 20%.

Current Solutions

Today, the dominating technology by far is pitch regulated variable speed technology with turbines that control the power and loads in a manner where there is a predominantly laminar air flow around the blade, and where there is a full-length blade pitching activated by hydraulic pistons or electrical motors in the rotor hub.

Some turbine designs are still combining the full length pitching with aerodynamic stall, as this result in low fatigue loads and simple power electronics. But this solution is losing competitiveness due to higher extreme loads and requirements for additional power compensation equipment in order to comply with some grid requirements.

Emerging Technologies

Emerging technologies for aerodynamic power and load regulation focus a lot on changing the aerodynamic lift and drag coefficients of the blade structure itself rather than merely changing the angle of attack.

Emerging technologies includes:

- Fast moving flap control mechanisms as seen on aero planes
- Microtab systems that controls the flow around the blade
- Morphing structures where the blade structure itself is changing shape
- 2-bladed turbines with partial length pitch

R&D Projects

APLR technology has a potentially very large impact on the competitiveness of the wind turbine manufacturer and can therefore be used to establish a significant competitive advantage. This has implications on the types of projects that should be executed outside the research departments of the wind turbine manufacturers.

Danish cross industry projects must focus on fundamental research topics including:

- Activation means such as piezoelectric materials or robust flap mechanisms
- Fundamental material research to enable flexible load carrying structures
- Calculation methods and tools for passively morphing structures where complex deformation patterns are achieved by directional fibres
- Aerodynamic tool development to enable accurate computation of impact of new technologies
- Iterative learning control systems to enable control of complex aerodynamic actuation means

Prototypes for demonstration purpose could also be beneficial for research institutes and universities, but would most likely only be interesting for smaller wind turbine manufacturers. This type of projects would however be good for maintaining and nurturing an innovative Danish R&D environment.

3.4.3 ADVANCED CONTROL SYSTEMS

Functions

The wind turbine control system has the purpose of controlling the wind turbine with a number of objectives while a number of constraints should be taken into account, these objectives and constraints are:

- Control rotor/generator speed corresponding to the generated power.
- Control generated power as close to the rated power as possible.
- Keep loads on the structure i.e. blades, tower, drive train etc. within the constraints both in normal operation as well as during extreme loads.
- Detect and accommodate faults in sensors, actuators and system components.

Target

> The target is to develop advanced control systems which lower the cost of energy of wind energy by enabling lighter structures through better load control and by increasing the availability of the wind turbines by advanced fault detection and fault tolerant control.

Current Solutions

The current solution is to control the wind turbines by using "simple" control systems which are highly adapted and adjusted to the wind turbine application. The control system controls the wind turbine by actuation through generator torque and pitch angles, and secondary by controlling the yaw motor(s). The control is based on a few measurements from the wind turbine.

Emerging Technologies

Research in the advanced control systems for wind turbines have taken different directions, some major trends are:

- Different types of individual pitch control to lower structural loads due to wind speed variations in the rotor field
- Control based on wind speed estimations or measurements inform of LIDARs etc.
- Different advanced control techniques like: Model predictive control, robust control, repetitive control etc. have been applied to the wind turbines
- Advanced fault detection and isolation and fault tolerant control for increased reliability and availability
- Model based control on wind farm level, either for power optimisation or power and load optimisation
- Adaptive control which adapts the controller to the operational conditions of the wind turbine
- Optimize component lifetime while generating as much power as possible
- Wind turbine controls using new actuators in the blades

In general most designs are based on model based methods which takes the different control objectives and constraints into one design. The wind turbine has multiple inputs and multiple outputs (MIMO). This also means that dedicated models for control design which takes different wind turbine aspects into account have been developed as well.

The potential in advanced control systems should be seen in the context of the wind turbine's other subsystems; it has a dramatic impact on the blades, tower, drive train etc. More advanced control will for example enable more flexible structures since loads are better controlled by the control system.

It is important that control systems work on wind turbine system level, where they can take the different components into account, use their strong sides and avoid their weak points. This leads to much more optimal design where the true potential of the wind turbine can be obtained. Otherwise large parts of the potential can be used on safety margins in the components. The advanced control system consequently works as a system integrator.

R&D Projects

Danish cross industry projects must focus on fundamental research topics. In these projects it is important to take the entire wind turbine and its components into account.

- Advanced model based control schemes which take component life time optimisation into account as well as generated power in the control design.
- Development of component life time models for control design.

- Inclusion of new actuators and sensors in the wind turbine control system
- Advanced fault detection, isolation and fault tolerant control for improved availability and reliability of the wind turbines
- Merging of "normal" control systems and safety control systems for more optimal fault accommodation
- Advanced handling of extreme event cases both in the wind and as well on the grid
- Model based control of wind farms which takes life time usage of wind turbines into account as well as power generation and grid support
- Wind turbine control for grid support

3.4.4 MECHANICAL DRIVE TRAIN SYSTEM

Functions

The Mechanical Drive Train System has the following main functions:

- Transfer rotor loads to nacelle structure, while providing one degree-of-freedom (rotation along main shaft axis) in order to transfer torque to generator
- On some concepts: Increase rotational speed
- Provide stopping torque to the drive train for some service operations

Target

> The target is to develop a Mechanical Drive Train System that has a 25% lower net present value of life cycle costs.

Current Solutions

In the late 90's, there were significant reliability issues with wind turbine gearboxes, but due to design improvements and increased understanding of dynamic behaviour of wind turbines the issues where significantly improved. This lead to very limited design changes and the dominating solution for mechanical drive trains in the 00's consisted of a gearbox and main bearing arrangement using either one or two spherical roller bearings.

A combination of some amount of continued reliability issues, high perceived risk, and offshore turbines with very high replacement costs, have meant that many companies started to seek alternate solutions in particular to eliminate the gearboxes.

In addition to this a quest for reduced top head mass has meant development of solutions that reduces or eliminates the main shaft.

The result is that drive train systems have diverged in multiple directions for the 10's, and there is no sign of convergence towards a dominating solution or technology.

For yesterday's dominating technology, which is still being used and developed on by many companies, the gearbox and main bearing arrangement constitutes 15-20% of the wind turbine CAPEX (not considering foundation and balance of plant). In addition to this, there are unfortunately still large repair and replacement costs related to the mechanical drive train, making it a significant contributor to CoE.

Emerging Technologies

Emerging technologies for the mechanical drive train include:

- Compact main bearing arrangement with low weight and cost.
- Alternate main bearing arrangements to cope with phenomena emerging in multi MW wind turbines.
- Torque split gearboxes enabling use of small diameter planetary stages as torque is distributed amongst more gear stages.
- Gearbox solutions with better load sharing between more than three planets.
- Variable transmission gearboxes as enabler for eliminating CAPEX and power losses in power electronics as gearbox can be directly coupled to medium voltage synchronous generator.
- Hydrodynamic and hydrostatic journal bearings for gearbox bearings.
- Bearing and gear steel as well as lubricants optimised for wind turbine environment.
- Improved condition monitoring systems to optimize service execution.

R&D Projects

The mechanical drive train has a significant impact on CoE. The main target is to achieve a cost competitive solution with low repair costs. Due to the historic issues with drive train reliability this will need to be a focus area.

Danish cross industry projects must focus on fundamental research topics including:

- Condition monitoring systems
- Fundamental material research in high strength steel subjected to rolling and sliding contact fatigue in wind turbine applications.
- Reliability improvement through component and system testing.
- Calculation methods and tools for dynamic simulations of bearings and gear contact.
- Advanced service concepts enabling low cost repair and refurbishment.
- Establish hardware (e.g. x-ray diffraction equipment) and methodologies for improved root cause analysis on failures.
- Drive train test facilities + nacelle test facilities + component testing + test engineering

3.4.5 ELECTRICAL SYSTEM (TRANSFORMER, GENERATOR, CONVERTER)

Functions

- The generator converts rotating mechanical energy into electrical energy

- The converter converts a varying voltage/frequency from the generator into a fixed voltage/frequency output synchronised to the power grid

    - Controls generator current and phase
    - Ensures speed range required of the turbine's controls
    - Control grid code compliance
        - Synchronises connection to power grid (voltage, frequency and phase)
        - Controls the turbine through low voltage ride through
    - Transfers energy to grid connection

- The transformer steps up the low voltage level from the converter to high voltage allowing connection to the distribution grid

Target

To develop more efficient system solutions and minimise lifecycle cost through standardisation

Current Solutions:

Transformer
The transformer is one example of many components that was not originally designed to be placed in a wind turbine but a standard shelf component that was also used in other industries to keep costs down. The opposite result proved to be the case after many transformer break downs and they are now designed especially for wind turbines. There are two types of transformer technologies used in wind turbines, the main difference lies in the type of insulation used. One type of insulation is made from insulation paper and some type of liquid e.g. mineral oil or silicon liquid (liquid insulation), the other less used is made from air and resin (dry insulation).

Generator
The dominant technology in the industry is a doubly-fed induction generator, and the squirrel-cage asynchronous generator, but new concepts are gaining market shares, i.e. permanent magnet generators in different topologies. Conceptual changes from high speed gearboxes towards hybrid and gearless system, causes a trend towards medium and low speed generators, causing different demands to the converter system.

Converter
The most commonly used converter concept for wind turbines is a two level back-to-back converter. Various new concepts exist like multilevel converters and matrix converters.

CoE reductions can be achieved by more cost effective components in the electrical system, especially the generator. On the short term, the solution is standardisation to bring down production costs, on the longer term it is new types of generators e.g. superconducting generators.

Emerging Technologies

Modularity of electrical interface by use of external containers hosting A: converter and B: transformer and switchgear. This is done to ease transportation and service and to bring down cost.

Transformers:

- Transformers for offshore use with synthetic ester (biodegradable and non-toxic)

- Transformers to incorporate the new large offshore turbines and a grid connection of e.g. 66 kV

Converters:

- Silicon Carbide IGBT (insulated gate bipolar transistors) solutions especially for solutions with many parallel modules

- Multi-level converter concepts

- Redundant/failsafe systems that can run at reduced power if a part of the converter or generator has failed

- Active filtering on power grid to improve grid power quality

Generators:

- Superconducting generators on the longer term

R&D projects

- Higher efficiency in production through a higher degree of standardised processes to start a serial production. This would lower production costs considerably

- Develop superconducting generators (in a minimum 5 year perspective) for the new large turbines. Development projects of this nature will combine a generic technology with an EU focus with an industry with large growth potential. This will require a matching level of financing from public and private sources

- Developing more cost effective, reliable and improved materials

- Permanent Magnetic generators using alternative materials

- Reliability and predictability of power electronics to ensure higher availability especially for 3, 6 and 10 kV converters and components

- Components and system solutions for turbine and grid up to 66 kV, this includes transformers, array cables, switchgears and arresters

- Generation of DC directly from offshore turbines could mean a 2% CoE reduction (blade-to-shore) from reduced transmission loss. Such a concept requires new solutions of both converter, transformer and transmission grid

- Overall optimisation of the conversion system from generator to grid. By designing an optimised system with focus on the interaction between single components of the system, savings can be achieved for the complete system.

3.4.6 STRUCTURAL ELEMENTS (HUB, SPINNER, NACELLE MAIN FRAME AND HOUSING, CRANE STRUCTURE)

Functions

Transfer loads between systems:

- Transfer load from pitch system to mechanical drivetrain
- Transfer loads from mechanical drive train to yaw system
- Protect other systems from weather conditions
- Transfers lightning to tower and foundation
- Provide crane foundation or internal crane system

Target

The R&D potential for structural elements on an overall basis is closely linked to load reductions from the rotor. An additional potential is use of materials, improved transport solutions and serial production. Use of new materials will result in reduced weight and cheaper components that are easier to transport

Use of new materials will result in reduced weight and cheaper components that are easier to transport

Current Solutions

The spinner and nacelle housing are made from glass fibre composites whereas the nacelle main frame and hub are made from cast iron. There are strict requirements for high quality materials especially for the hub and main frame with regard to yield and tension strength. The components are exposed to very strong forces and loads as well as large temperature variations.

Emerging Technologies

An estimated 10% nacelle weight reduction can be achieved by exclusively using composite materials also for the main frame. This will lead to reduced loads on the tower and foundation and make the assembled nacelle easier to transport.

Serial production of the structural components will also lead to cost reduction as will standardised transport solutions of the large and heavy objects.

R&D Projects

- Use of composites for all components
- 30 % rotor weight reduction
- Standardised transport systems
- Serial production

3.4.7 SUPPORT STRUCTURES

This section only focuses on the tower. Foundation solutions for offshore use are described in detail in the English version of Megavind's offshore strategy.

Functions

- Transfer loads from yaw system to the ground without causing problematic deformations or vibrations
- Provide access to nacelle for service personnel
- Protect electrical components from environment (only some configurations)
- Provide cable route for power, control and communication cables

Target

To develop taller towers and increase their structural strength while at the same time keep dimension and weight at a level where they can be transported from production to installation site.

Current Solutions

- Steel tube towers that are split in sections of various length
- Bent and bolted steel shell towers up to 140 m (onshore only)
- Steel lattice towers can reach 160 m
- Concrete towers, divided into sections up to 150 m
- Hybrid towers, combination of steel and concrete sections – up to 120 m without transportation issues

Emerging Technologies

Focus on tower technology is mainly to bring down material costs and to meet transportation challenges. Concrete solutions are cheaper than steel and can be cast on-site – eliminating transportation issues. Hybrid solutions combine steel and concrete. The tower base – with a wider diameter – is made of concrete and the top of the tower consists of steel sections.

In 2011, two Danish RD&D projects received public funding. One is a concrete/steel hybrid solution the other is a concrete tower.

R&D Projects

- Cable stayed towers
- New welding codes
- Separated flanges
- Tower door moved to foundation (below ground). This will increase the strength of the tower and reduce material use. Can be combined with a hybrid tower.
- Towers without flanges
- Platform and lift designs

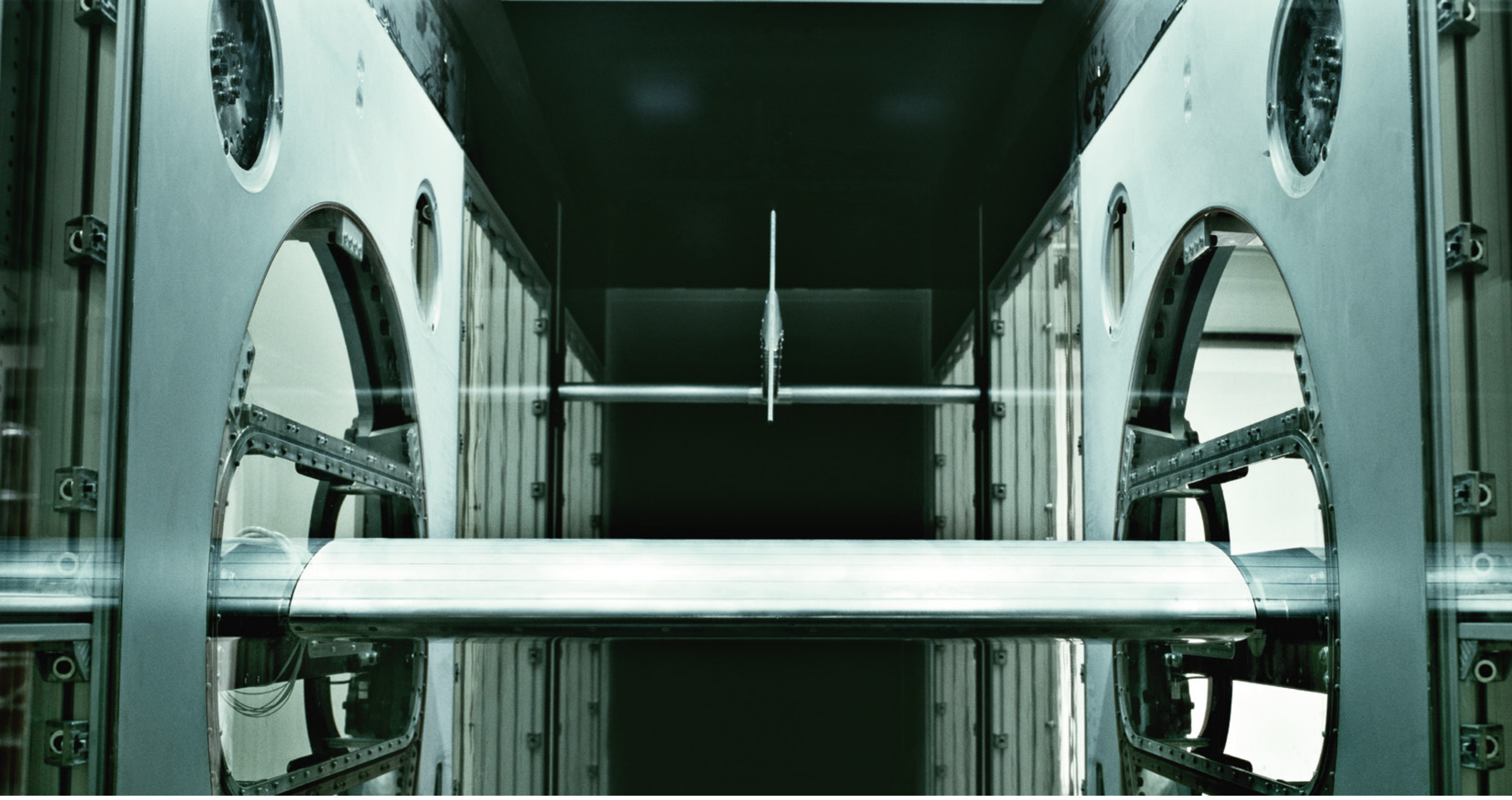
PHOTO: BENT NIELSEN

3.4.8 SUMMARY

Components and Systems	Development Opportunities
Blades	Aero-elastic tailoring where deformation patterns are optimized to increase aerodynamic efficiencies and better control of load and deflections Passive regulation where there is coupling between bending deflection and twist or lift. More automated manufacturing processes Better materials
Aerodynamic Power and Load Regulation	Fast moving flap control mechanisms as seen on aeroplanes Microtab systems that controls the flow around the blade Morphing structures where the blade structure itself is changing shape New blade and rotor concepts, e.g. 2-bladed turbines with partial length pitch
Advanced Control Systems	Different types of individual pitch control to lower structural loads due to wind speed variations in the rotor field Control based on wind speed estimations or measurements in form of LIDARs etc. Different advanced control techniques like: Model predictive control, robust control, repetitive control etc. have been applied to the wind turbines Advanced fault detection and isolation and fault tolerant control for increased reliability and availability Model based control on wind farm level, either for power optimization or power and load optimization Optimize component lifetime while generating as much power as possible Adaptive control which adapts the controller to the operational conditions of the wind turbine Wind turbine controls using new actuators in the blades

Components and Systems	Development Opportunities
Mechanical Drive Train System	Compact main bearing arrangement with low weight and cost Torque split gearboxes enabling use of small diameter planetary stages as torque is distributed amongst more gear stages Gearbox solutions with better load sharing between more than three planets Variable transmission gearboxes as enabler for eliminating CAPEX and power losses in power electronics as gearbox can be directly coupled to medium voltage synchronous generator Bearing and gear steel as well as lubricants optimized for wind turbine environment Improved condition monitoring systems to optimize service execution
Electrical System (Transformer, Generator, Converter)	Transformers: New transformer for offshore use with synthetic ester (biodegradable and non-toxic) Transformers: New transformers to incorporate the new large offshore turbines and a grid connection of e.g. 66 kV Converters: Silicon Carbide IGBT (insulated gate bipolar transistors) solutions especially for solutions with many parallel modules Converters: Multi-level converter concepts Converters: Redundant/failsafe systems that can run at reduced power if a part of the converter or generator has failed Converters: Active filtering on power grid to improve grid power quality Generators: Superconducting generators on the longer term
Structural Elements (Hub, Spinner, Nacelle Main Frame and Housing, Crane Structure)	Use of lighter materials e.g. composite materials in the Main Frame
Support Structures [6]	Bring down material cost and weight, e.g. by using hybrid solutions

6 Specifically meant as support structures (towers and foundations) for onshore wind turbines. Foundation solutions for offshore use are described in detail in the English version of Megavind's offshore strategy.



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